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ABSTRACT

One area explored in the second (in-depth) phase of the Learning in Science Project was "children's science," defined as views of the world and the meanings for words that children have and bring with them to science lessons. The investigation reported focuses on students' (N=43) views of physical change associated with boiling, melting, dissolving, evaporating, and condensing. Data were obtained using the "interview-about-events" method in which students were asked to describe and then explain what happened during each of six events. Student responses are presented, discussed, and analyzed for each event: bubble formation; steam condensing on saucer; water evaporating from saucer; sugar dissolved in water; condensation occurring on outside of jar containing ice; and melting ice. One finding reported indicates that although students can often associate the appropriate technical term with an event (such as "boiling"), many students, including older ones, have no sound scientific concepts underpinning these labels. In addition, several clearly identifiable examples of "children's science" were found (such as believing that oxygen/hydrogen are found in bubbles of boiling water), emphasizing the point that teachers need to be aware that children's views can be modified by science lessons in ways not intended. Implications related to understanding of the particle model are also discussed. (JN)

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LEARNING IN SCIENCE PROJECT

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PHYSICAL CHANGE

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WORKING PAPER No. 26

In our view successful science teaching requires an appreciation not only of the scientists' view of the world, but also an appreciation of the language, the beliefs and the expectations which children bring with them to science classes. This working paper has developed from a study carried out in the in-depth phase of the Learning in Science Project and is one of a series of papers which explores aspects of Children's Science (see Working Paper No. 14). It is our hope that these papers portray children's views of the world and meanings for words in a way which will be useful to teachers and to curriculum developers.

In the action-research phase of the project it is our intention to attempt to build practical and useful teaching strategies based on the findings of the in-depth phase of the project. For this reason we are actively seeking comments on the findings we have detailed, and seeking information on the variety of ways teachers develop ideas associated with the topic under focus in this paper.

We would be grateful if comment and/or information could be forwarded to

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PHYSICAL CHANGE

A working paper of the Learning in Science Project

Mark Cosgrove and Roger Osborne

April 1981

Introduction

This is an account of an investigation into children's views on some physical changes associated with boiling, melting, dissolving, evaporating and condensing. The investigation took the form of a series of tape-recorded interviews with individual children chosen from classes ranging from Standard 4 to Form 7. The interviews were undertaken mainly at the children's schools, but not in their classrooms. Generally each child left a science lesson to be interviewed, and the selection of children to be interviewed was made by the teacher. The interviewer requested the teacher to select children who were not exceptional. Usually the interviewer and the young person being interviewed were the only people present, although on a few occasions there was an observer present. Each interview lasted about half an hour.

The Interview Method

The interview method is a development of the 'interview about instances' method [Osborne and Gilbert 1979] used to investigate children's meanings of scientific words (eg 'force'). This development is similar to the 'interview about instances' method, and is known as 'interview about events'. In this type of interview [Osborne 1980a, 1980b] a particular set of events, for example water boiling, condensing, ice melting, are demonstrated to the interviewee. The child is asked to describe what he sees happening and is then asked to explain, in his view, what has happened. Having discussed the child's view of the event, the interviewer then investigates what the child knows of the scientific view of the event.

The situations, and the focus questions used to elicit children's views were:

1. A jug or kettle with water boiling in it.
   The question: What do you see in the jug?
   then : What are the bubbles made of?
   then : What is "boiling"?

2. Steam from the jug condensing on a saucer placed above the jug.
   The question: What is the steam made of?
   then : What is this on the saucer?

3. Water evaporating from the surface of the saucer.
   The question: What has happened to the water on the saucer?

4. Hot water is poured into a cup and a teaspoonful of sugar is dissolved in it, with stirring.
   The question: What has happened to the sugar?

5. Blocks of ice placed in a household jar and the lid screwed on. After a time moisture from the air condensed on the cold part of the jar.
   The question: From where has the water on the outside of the jar come?

6. A block of ice placed on a teaspoon and its melting observed.
   The question: What is happening to the ice on the spoon?

Each of these focus questions was in turn followed by further questions generated by the interviewer's reactions to the young person's first response. The interviewer attempted to find out the young persons own views on these situations.

In the six situations listed above, the underlined word indicates the scientific event on which each part of the interview was focussed. Figure 1 is a schematic view of the interview schedule. The numbers refer to the operation sequence and not directly to the focus questions listed above.

Each interview was transcribed from the tape recording by the interviewer. A total of forty three interviews were transcribed.

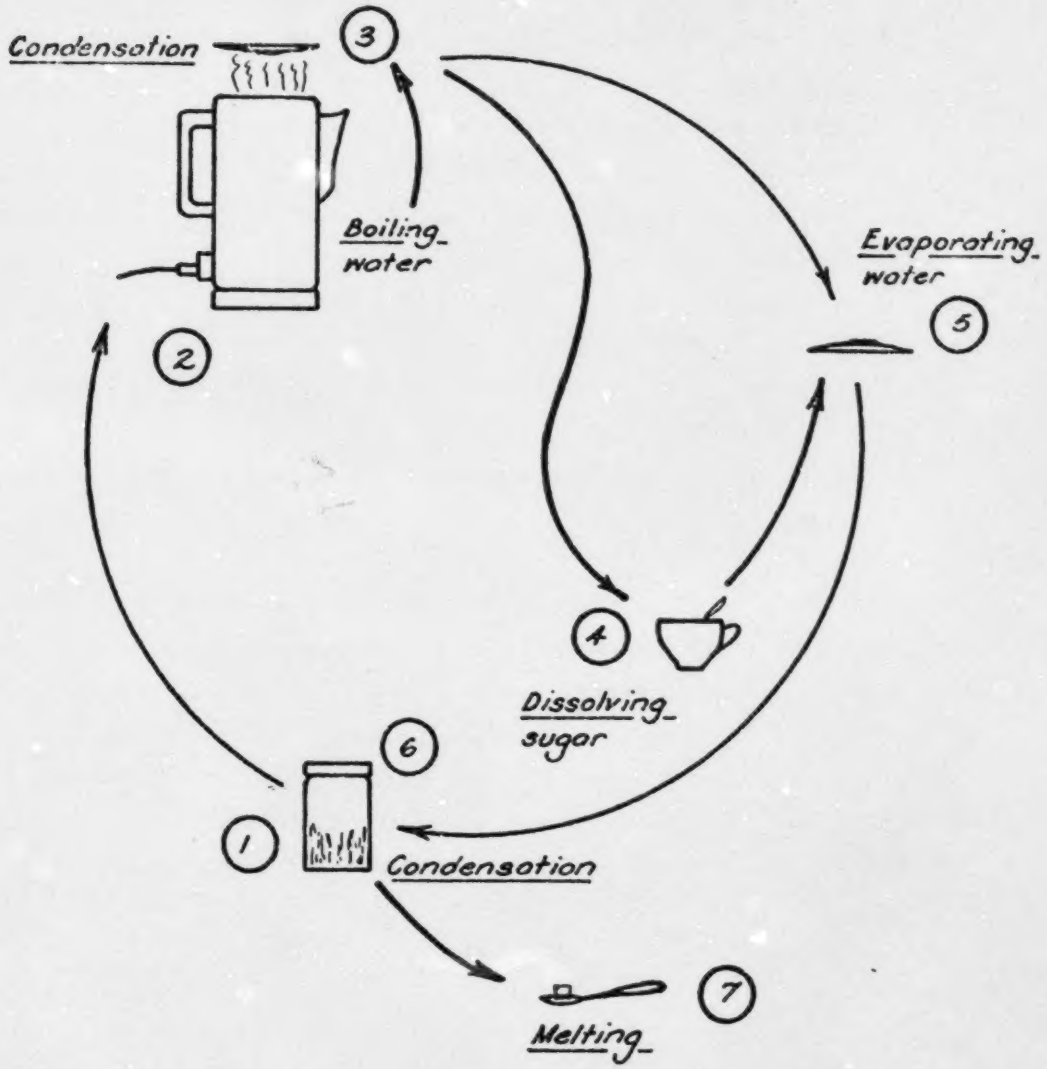

Figure 1: The interview sequence for "physical change"

The forty-three interviews used in this study came from

(a) two people who were eight years old (encoded 081, 082)

(b) seven people who were ten years old (encoded 101, 102, 103, 104, 105, 106, 107)

(c) one person who was eleven years old (encoded 111)

(d) six people who were twelve years old (encoded 121, 122, 123, 124, 125, 126)

(e) nine people who were thirteen years old (encoded 131, 132, 133, 134, 135, 136, 137, 138, 139)

(f) four people who were fourteen years old (encoded 141, 142, 143, 144)

(g) six people who were fifteen years old (encoded 151, 152, 153, 154, 155, 156)

(h) five people who were sixteen years old (encoded 161, 162, 163, 164, 165) and

(i) three people who were seventeen years old (encoded 171, 172, 173)[1]

When the interviews were transcribed they were searched through in order to extract the responses to the focus questions. These responses were then collected together into groups according to the information in each response. These groups were generated by the writers, and they represent the writers' views on the children's responses. Usually each collection of responses was broken down into four to eight groups. This process is best understood by examples, and these follow.

EVENT ONE <u>The bubbles</u>

Children were asked "what do you see in the jug?". Invariably the response was "bubbles". The interviewer followed this by asking "what are the bubbles made of?" Responses included

> "I don't know. (Haven't you thought about that before?) No ... just bubbles. (What do you think they could be made of?) Heat." (104)

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1 The 15 year olds were studying Science, the 16 and 17 year olds were studying UE and UB Chemistry.

(If you could see inside a bubble what would you see?) "I'm not too sure ... nothing really. (Does that mean there is nothing there?) No, it's just that they are a form of air". (143 - also 102, 105, 111, 124)

To many children there was a problem as to how the bubbles acquired the air. For some it was obtained from the air above the water. For example

"(What are the bubbles?) Air pockets ... Hot air rises, grabs the air and takes it back to the element. When the water comes up to the surface, it cools and will go down again and might have sort of trapped some air in it..." (162).

But to others the air came out of the water,

"The heat of the element could turn some of the water into air..." (123)

"Air (Where does the air come from?) Water" (124)

(So these bubbles are made ...?) Out of the water. (And they consist of?) Air." (154, see also 153, 152)

Some older children could integrate their knowledge about oxygen, hydrogen and other gases into the view that the bubbles are made "out of water"

"(How do you see what's going on?) Separating I suppose ... the hydrogen and the oxygen..." (155)

"(What are the bubbles?) Air pockets. (Bubbles of air?) Yes. (So where has the air come from?) The water, it is made up of oxygen and other elements in the air. (Water is made of oxygen?) Oxygen, hydrogen and nitrogen, and its also got helium and a few other things. (That's inside the water?) Well, it's in the air, but in the water these things do also exist." (152)

From an analysis of all the interview transcriptions on this focus question, we recognised seven different groups of views. In some responses, the clear view was that the bubbles were made of heat. Others thought the bubbles were oxygen and/or hydrogen from the water. Some thought the bubbles were made of steam.

The full analysis is shown in this table:

TABLE 1

"What are the bubbles made of?"

View on this	Responders
heat	104, 125
air	081, 102, 105, 122, 123, 124, 131, 135, 137, 138, 139, 143, 152, 162
water	101, 106, 107, 111
oxygen and/or hydrogen from the water	141, 142, 151, 155, 171, 173
steam	132, 154, 165, 172
particles	161, 171, 172
oxygen from air	163

The responder 171, a seventeen year old, is underlined because he appears in two categories. This can be explained if it is borne in mind that the interviews were sometimes discursive because the interviewer, to make sure he clearly recorded the young person's views on a particular event, often came back to that topic. In this situation, the interviewee would, typically, elaborate on his previously stated views, and in this elaboration might show a wider set of views than in the initial response to the focus question.

The listing of responders in this table, and in those following is not considered to have statistical significance over and above the point that these responses indicate trends in the views which children have of the particular events. Sometimes, too, a responder does not appear in the table which shows our analysis of a focus question (for example, in the table above, Table 1, the child "082" is not listed). This is for one of two reasons:

(a) the response was completely idiosyncratic (the view is peculiar to, or specific to, one person), or

(b) the interview transcription indicated that the interviewer gave very little attention to that point.

Notwithstanding reason (a), we sometimes include what appears to be an idiosyncratic view if it seems to us to be more than a little interesting.

In Table 1, we have listed responder 163, as he identified the bubbles as being oxygen from the air. This particular interview went like this

> "(Why are there bubbles in the jug?) Well, they're there because the water's warming up and the oxygen and the gases are being driven out. The oxygen and the gases or whatever's in there is being driven out because the liquid holds less gas at high temperature." (163)

An inspection of Table 1 will show that most of the younger children viewed the bubbles as being "heat", or "air", or "water". Many of the older children viewed the bubbles as "air". As we have seen, students of fourteen years of age and older were keen to bring in their knowledge of oxygen and hydrogen, and of particles. Notwithstanding this we consider that one of the ideas which presented itself regularly was the view that if matter became invisible, it was because it turned into air, and that steam is a form of air.

Most of the senior students, in forms six and seven, had studied phase changes, and the kinetic-molecular theory, in their coursework. Nevertheless, only three of our small sample were able to use the ideas of particles in this situation. Ideas about "change of state" were rarely encountered.

> "(What are they? (the bubbles)) Gas escaping. Water turning into steam. Well, the bubbles, when they burst, it's water being turned into steam, and that's why they're escaping. "(How did the bubbles form?) Molecules moving around, they're getting faster and faster, and they want to break out because ... they're strong enough to break out." (172)

Some of the senior students used their knowledge of oxygen and hydrogen, but were still influenced by egocentric views. One Form seven student said

> "... well, I think that's what inside the bubble ... I think I said it was oxygen ... but if you put your face over that and breathe in ... it doesn't seem that you can breathe too well ... so I don't think there is much oxygen ... it would be more hydrogen in the bubbles so there is water vapour and hydrogen." (173)

Six of the older students explained the contents of bubbles in terms of a heat-caused splitting of water into hydrogen and oxygen. Is there some parallel to electrolysis here? Do students think that if electricity can split water into oxygen and hydrogen, heat will do the same?

Another aspect of this event, the boiling water in the jug, enabled interviewers to examine children's views of boiling. If in a response the term "boiling" was used, we normally explored the matter further. The interviewers did not introduce the term "boiling". Here is a selection of children's views

> "The water is boiling. (How do you know its boiling?) The water starts to bubble and smoke starts to come." (103)

> "... It's boiling ... it's real hot ... hot as it can go probably ... the bubbles come to the top and burst open and makes steam come out." (124)

> "The element is heating the molecules in the water making them expand and move around faster and they move off into steam. (What do you mean by expand?) They move further apart from each other." (142)

> "It's boiling. (What does boiling mean to you?) It's when all the atoms in the water ... the liquid are racing around really fast because they are getting hot and ... some of them are going off in vapour because they're turning into gas." (156)

> "(What's boiling?) It's when they've got ... when they're changing from a liquid to a steam ... (How do they change?) Temperature changes them. (Do you know how?) Um, particles banging against each other ... one's moving faster than the other, the other'll get a bigger kinetic energy." (162)

The groups of views presented to us are summarised in Table 2.

TABLE 2

"What is boiling?"

View	Responders
it is water bubbling	101, 102, 103, 104, 105, 106, 107, 111, 121. 122, 123, 124, 125, 132, 133, 135, 137, 138, 139, 141, 143, 144, 151, 152, 154, 155, 162, 163, 171, 172, 173
it is steam coming off	102, 103, 107, 124, 135, 154, 164, 165
it is water getting hot	105, 111, 124
it is particles moving	142, 143, 152, 153, 156, 161, 163, 164, 171
it is particles escaping	156, 161

Here, the younger children responded in terms of the phenomena observed. Older children normally suggested ideas linked to movement, but the number who suggested that a change in phase or state had occurred was low (two responses). We suggest that children view boiling as an event caused only by heating a liquid. There was no recognition that pressure has anything to do with a liquid boiling. It would seem that few of the older children have seen a liquid boiling under reduced pressure, despite the impact that this effect can have on learning about liquids changing into gases.

EVENT TWO Steam condensing on a saucer

Following the discussion about boiling, the focus of the interview shifted to the steam and the condensation of the steam on the plate. When asked what the stuff coming off the water was most students said "steam".[2]

2. However we were interested in the response of one interviewee, who stated "Water vapour. (What is water vapour?) It's another name for steam but you are not allowed to use the word steam."

In response to the next question "what is the steam made of?", the most common answer identified steam as a form of water. For example

> "Well, the hot water goes hot and then it just rises up to steam." (106)

Several children thought that air and steam were the same thing:

> "Probably brings out the air out of the water." (105)

> "... Steam. (What is steam anyway?) Air. (Anything else?) No." (125)

> "Steam. (What is that?) Hot air. (The steam is air?) Yes." (137)

> "... Water changes into gas ... air ... steam." (138)

Some of the children used their knowledge of hydrogen, oxygen, molecules and particles to account for steam. Although these were mainly older children, one twelve year old replied

> "(You have talked about at ms, are atoms of steam different from atoms of water?) I dor t think so ... I am not sure ... well I suppose the water atoms would be different to the steam atoms because the water has to change its form ... so the atoms would have to change their form as well ... get smaller." (123)

Other views included

> "It is made out of the water ... it consists of particles of water but they are further apart ... the atoms of water are further apart." (142)

> "A vapour forms which is steam ... it is water that has changed from a liquid state into a gas state ... steam is just the water reacting with the atmosphere. (What does this gas state consist of?) It consists of the same particles as in the water except that they are moving a lot faster and therefore they are not as dense and therefore they are steam ..." (152)

"(What is the difference between particles of water and particles of steam?) Yes ... well looking at them there is a difference. (So they are different sorts of particles are they?) Yes, you know how they are grouped ... look the liquid has got particles close together ... but in a gas they are spread out. (Same particles or different particles?) They must be the same particles ... they are just situated differently." (154)

"The water molecules are kind of packed more tightly in the water than they are in the steam. (What is a water molecule?) Hydrogen and oxygen ... one hydrogen atom and some oxygen atoms ... something like that." (153)

A seventh former had an interesting view, though

"... water vapour ... particles of water that have left the water that is in the jug through heat. (It is connected to the bubbles?) Oh, it is not coming out of the bubbles ... when the bubbles rise to the surface the water that is surrounding leaves with the bubbles and evaporates." (173)

Table 4 summarises the ideas we recorded on how these children thought about 'what steam is'.

TABLE 4

"What is steam made of?"

View	Responders
it is water	081, 101, 102, 104, 106, 111, 121, 122, 123, 124, 132, 133, 139, 143, 144, 152, 153, 154, 155, 161, 162, 165, 171, 172, 173
it is smoke, mist	103, 111, 152
it is air	105, 107, 125, 135, 137, 158
it is oxygen and hydrogen	151, 156, 173
it is molecules, or particles	123, 141, 142, 152, 153, 154, 164, 172

In the second part of the discussion related to EVENT TWO children's answers to the question "what is this stuff on the saucer?" permitted us to explore children's views on the process of a gas condensing to its liquid.

To some the steam had changed into a water type substance. For example

> "(You reckon that's water - same as the water in the kettle or different water?) Different water. (Different water? How is it different?) I don't think we drink this kind of water. (You wouldn't want to drink this?) No. (Do you reckon there's something wrong with that water?) Well, I don't think anybody drinks steam water."
> (106)

> "(You think it's water?) Um ... steamy water. (Steamy water - that's different from ordinary water?) Oh, no ... looks like real water. (You feel it.) Feels like real water. (Feels like real water? Perhaps it is real water?) Yes ... the problem is - where does it come from?"
> (105)

To others it had just changed back to water. For example

> "Water vapour comes into it [the saucer] ... and seeing it is cold it is going to turn back to water."
> (111, also 121)

> "All the hot steam has come up and it has gone on to the saucer ... and it has gone cold again. The steam has changed back into water." (122, also 124)

To others the plate was more sweaty than wet. For example

> "It makes it sweat ... (Why do you call it sweating?) When we are hot we sweat. (Did the plate get hot?) No, just a bit warm." (102, also 104)

> "... It's hot and it's just like you're running and your sweat in that its hot ... and it's just gone on to the plate ... you get all hot and sweaty just the same as the plate."
> (135)

One thirteen year old found it all rather puzzling

> "(What is making it wet?) The hot air from the steam ... (Is this hot air on here?) Yes ... and water. (Where did the water come from?) The steam, but I don't know how ... I have never thought about it ... the steam is not coming out wet until you put something over it really ..."
> (137)

The older students introduced technical terms like oxygen, hydrogen and particles. For example

"Well, water has been heated and the atoms of oxygen and hydrogen are rising up from the water. (Separately?) Yes, separately, and when they hit something they sort of join together and form little drops of water."
(141)

"... The cold plate has condensed the steam ... the steam has cooled ... and the atoms and molecules are closer together."
(142)

"It's quite cold ... and it is wet ... the steam has turned back to water. (What about the particles?) They have just gone back to what they were to start with."
(154)

"The particles ... of, well, ... the vapour hits this colder material which is this plate and they come together on it ... and turn back into water ... (The same particles?) The same ... but in a different form." (173)

"In the liquid, I think the hydrogen, the water kinda molecules are bonded together closely. When it's heated up these bonds are broken. They go into gas. They go up. They hit this and they cool down and the bonds join back together and form liquid water. (Why should they?) Because they're attracted to each other. (But they weren't in the gas?) No ... because they've got ... they're too ... they're moving too fast to join together. (So you connect breaking bonds and movement do you? Or is that not so?) No, um, bonds are broken 'cause enough energy is given to them to break."
(163)

"(You mentioned 'condense', what do you think is going on there?) Well, its sort of the reverse of what's happening. You don't just get one water molecule on the plate, you get water molecules colliding with the plate at the same time, and when they collide, well they lose energy and become water because - they have less energy ... not moving as fast, and when they do collide then the molecules get the most stable state, they form up with links between each molecule, and you get the water droplet as a result."
(172)

Table 3 is a summary of our interviews.

TABLE 3

"What is this stuff on the saucer?"

View	Responders
it is water	101, 105, 106, 124, 138, 139, 143, 144, 152, 153, 154, 155, 162, 171
it is water (by heat loss)	111, 121, 122, 133, 151, 156, 161, 163, 164, 165, 173
it is wetness, damp, "condensation"	107, 123, 125, 141
it is smoke, sweat, steam	102, 103, 104, 135
it is oxygen and hydrogen	141, 156
it is "atoms, molecules, or particles"	132, 142, 154, 161, 163, 172, 173

Again, those who sought to explain their observations using technical language generally became confused. They seemed unable to use the scientific terms with understanding. In particular, ideas to do with particles moving and colliding were ostensibly understood by older children but continued probing did not produce scientific explanations of condensing, in terms of intermolecular forces or loss of kinetic energy.

EVENT THREE Water evaporating from the saucer

The focus question here was "what has happened to the water on the saucer?".

This question enabled us to explore children's views on evaporation. In this instance, a few drops of water on the top of the saucer were observed over a period of time to disappear.

All students were able to relate this instance to a drying process, so this analysis looks past this specific term, and attempts to find some meanings for the words 'drying up'.

A sample of views follows. First there were those who considered it had "just gone". For example

"It has dried up. (Where has it gone to?) Just dried up." (081)

"I think it would just dry up ... it just well disappears ... gone." (103)

"Gone forever." (102)

"Like when it rains the cloth gets wet, and on a sunny day it just disappears." (101)

"Probably gone into the plate or something like that." [3] (101), also (106, 105)

Others considered it must have gone into the air. For example

"Probably steam comes up from the plate but you can't see it. (Where does it go?) To clouds in the sky ... when the clouds get full it rains." (124)

"(When it dries up is it still water?) No. (What does it change into?) Air." (125)

"(Where has the water gone?) I dunno ... it's just in the air ... its turned into a gas. (What's the gas?) I dunno. (What does gas mean to you?) A gas is a substance in the air ... there's not just gas in the air. It's also underground ... gas is just a thing you get in science ... I dunno ... it's hard to say." (135)

"... Or it might have just dried up. (What do you mean by 'dried up'?) Oh, well ... when the air goes past it might have just taken some of it up (into the air). Like erosion." (153)

"It goes into the air ... it is like boiling but it doesn't need as much heat." (142)

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3. Since the interviews were recorded one of us (MC) has looked further into this idea. Some children of 11-12 years of age have this view, too. The situation was examined by (a) wiping ethanol onto a piece of metal - to clean it, actually, and then watching it disappear, and (b) placing some drops of ethanol on the palm of the hand, and, again, watching it disappear. The responses were "It must have gone into the metal (or the hand)".

To a number of older students the water had "broken down" into smaller particles:

> "It has evaporated. (What does that mean?) It has mixed in with the particles of air ... it is almost like that sugar thing there. (So what has happened to the bits of water on there?) They have broken down into small particles. (What sort of particles are these?) Gas. (What would the gas be?) I don't know ... I think it has probably separated into hydrogen and oxygen gas." (155)

> "... Into the air ... it doesn't go into steam ... it just dries up ... (Where is it now?) Not in the steam form because it doesn't look if it has gone up in the water state - it must have split up because you couldn't sort of see steam or anything rising. (So when you say split up ... what do you mean by that?) Into the hydrogen and the oxygen molecules ... the water molecules break into their separate atoms." (151)

> "Just evaporating into the atmosphere which has a slightly higher ... pressure ... temperature ... it is just warming up evaporating. (So what is actually coming off here?) Very fine vapour. (Does it stay as water?) I don't really know ... I think it just breaks down into its initial compounds which are hydrogen and oxygen ... and they are now separate." (173)

Finally there were those students who had the idea that water particles moved into the air.

> "Well, the heat from the water underneath has just made it keep evaporating. (Evaporating? Let's have a look at that idea.) Evaporating? Well, it's just another way of saying ... um ... from water turning into steam going away as a gas. (How would water turn into steam?) Well, steam's just the gas form of water, and when it gets to a certain temperature it'll start ... um ... being given off as a gas. (Yes?) Steam gas. (Would it evaporate if we left it over there?) Yeah. It'd take longer. (OK. How would it happen then?) Um ... it'd still be the same sort of idea just take longer because it didn't have the additional heat from underneath. It'd still just eventually turn into water vapour and disappear. (How does it turn into water vapour?) It's ... it's when it um got a certain temperature, when its so hot (um) it'll turn from a liquid into water vapour. It'd probably be, if it was just sitting over there, um, the atmosphere pressure would heat certain particles on the very surface of the water, and they'd heat up and go off." (162)

"... The molecules have moved even further apart and gone off the plate ... the molecules have bounced off the plate into the air." (156)

"Parts of molecules are getting energy from somewhere and flying off ... (The molecules of?) Water. (Where do they get this energy from?) They've got some anyhow ... I don't know where they get it from. Perhaps what they've got is enough. They might get it from each other, or perhaps the air around has got it - I don't really know. Other molecules hitting it. The air ones, hitting them off." (165)

This focus question (what has happened to the water on the saucer?) enabled us to find out if children held clear views on the distinction between evaporating and boiling. A number of the older children were in difficulty with this line of questioning. We did not detect any views among the older children on "vapour pressure" and were surprised that the "dryness" in a refrigerator and the drying of foods in a refrigerator was not linked to evaporation. It was seen as a thermal energy linked process only.

Again, some children regarded air as the gas form of steam.

Table 5 summarises our findings.

TABLE 5

"What has happened to the water on the saucer?"

View	Responders
it disappears	081, 101, 102, 103, 104, 107, 122, 137, 171
it goes into the plate	101, 105, 106, 141
it goes to the clouds	124, 144
it's in the air	106, 123, 135, 138, 139, 142, 151, 153, 154, 155, 156, 173
it's turned to oxygen and hydrogen	151, 155, 173
the molecules/particles have moved away	142, 156, 161, 162, 163, 164, 165, 172

EVENT FOUR A teaspoonful of sugar is dissolved in water

The focus question here was "what happens to the sugar?"

Frequently young children will give a simple "observational" answer to this type of question:

"It goes down to the bottom of the cup .... Then it kind of fades." (107)

Some students used the word melting in their answers,

"When it gets into the water it kind of melts down ... and then it dissolves into the water."
LATER
"It is just how I think about it."
(124)

"The sugar is dissolving ... the water is sort of melting the sugar crystals. (Are melting and dissolving the same to you or different?) It means the same sort of thing."
(138)

"Um ... because the sugar has a large surface area, when it's put in the hot water it, ah melts it quicker, and then it just dissolves into the solution."
(161)

"(What happens when it melts?) Well, the little grains of sugar is made up of lots of things and the little things just come off and get smaller and smaller and smaller."
(103)

Most students used the word dissolve somewhere in their responses. A selection

"The sugar has dissolved ... sort of broken up into tiny pieces so you can't see it." (081)

"Dissolving. (What does that mean?) Sort of disappears ... it sort of mixes in with the water ... sort of soaks it up and it disappears." (111)

"Yes, the sugar is not there but the taste of the sugar is there." (122)

"Dissolving ... the sugar when it gets hot ... I suppose you could use the word evaporates again ... it goes into the water and makes the water sweet."
(123)

"Sort of mixed in with the water ... invisible ..." (125)

"The sugar is dissolved into the water ... oh, its been broken down into small bits that spread through the water." (131)

"(Is the sugar still there?) No. It would have dissolved into the water ... the sugar has just combined with all the water to make that substance ... the sugar and water is combined." (126)

"The sugar has dissolved in the water ... (What do you mean by that?) It must have been hot and the crystals have gone all hot and evaporated." (134)

"The sugar's all mixed up and getting dissolved ... it is going invisible ... it's sort of developed into water ... a clear sort of mixture that mixes in with the water." (136)

"(What does dissolve mean to you?) Oh, if you put something with another thing they both join together ... it's just got rid of all the lumps and gone with the water. (Is it still there?) Yes, but you don't see it because it is all mixed in ... (Some things don't dissolve?) Like a stone cause it's a hard substance." (135)

"They've become so tiny it's just mixed through ... as simple grains. (That's fine but you don't see any difference between what's happened there and melting?) You can't really explain dissolved actually ... I don't think so ... it's only one word you can't explain it." (133)

Some older students also introduced the idea of molecules into their explanations

"The sugar is dissolving ... the compounds are broken down into molecules." (173)

"Um, sugar molecules are being pulled apart by the water molecules and diffusing them through the water, its sort of an equilibrium reaction."
LATER
"... the (sugar) crystal's breaking apart 'cos it's got weak covalent bonds between each molecule, and they're breaking apart by the water. (How does the water do it?) Ah ... they're sort of polar, polar attraction probably." (162)

"... Now, why would the sugar (molecules) rather be next to water? And why not next to one another?"
LATER
"Well, the water molecules are now between the sugar molecules, that I know, or believe. Um ... Is there some attraction between a water molecule and a sugar molecule? Yes, I think there must be."
LATER
"... The hotter it is, the more would dissolve because more sugar would ... become separated. A certain amount of energy is required to separate sugar molecules from one another, to break chemical bonds. And so, the hotter the water was, the more would be dissolved because the more sugar molecules would be broken apart." (172)

Older children also used a particle model in many of their initial statements about dissolving. Some of the younger children did, too.

"They become so tiny it's just mixed through ... as simple grains." (133)

"Water molecules have gone between the sugar ..." (139)

"The sugar molecules all split apart and then their molecules just mix." (156)

"Well, it doesn't actually dissolve ... it just gets broken up ... into such tiny ones that you can't see it anymore." (151)

"The hot water breaks the bonds between the molecules. (Have you any idea how?) Ah, the energy of the hot water. Um ... also ... if it's cold water and mixed vigorously it still breaks down. I think they're really fairly weak." (161)

An interesting view of the role of hot water in dissolving was presented mainly by children in the middle of these age groups.

"The hot water is melting the sugar ... breaks into tiny pieces and dissolves the water because of the heat ..." (124)

"(What's happened to the bits of sugar?) They are broken up with the heat ... dissolved." (137)

"Um ... maybe the heat of the water makes the molecules inside the sugar move further apart." (142)

"Um it's ... 'cause of the hot its become um sort of melted and become (later) disintegrated away into the water." (133)

"They are dissolving ... heat is causing them to dissolve."
(154)

Table 6 is a summary of views.

TABLE 6

"What happens to the sugar?"

View	Responders
it melts	102, 103, 101, 111, 124, 121, 137, 138, 134, 135, 133, 139, 144, 152, 161
it is broken up; gets smaller and smaller, fades, disappears	081, 104, 103, 107, 122, 125, 121, 131, 133, 151, 156
it dissolves, makes a solution	102, 107, 106, 105, 111, 123, 124, 126, 121, 138, 134, 136, 135, 133, 132, 143, 144, 154, 153, 155, 161, 162, 163, 164, 165, 171, 172
particles are involved	133, 139, 144, 142, 151, 152, 156, 161, 162, 163, 164, 165, 172, 173
heat breaks it down	123, 124, 137, 134, 133, 143, 142, 152, 154

Most children recognised this event as a dissolving process. As in all of these events, the interviewer probed this view, and a significant group of responses indicate that children sometimes look on 'melting' as the first step in 'dissolving'. While this view would not be acceptable in science, it seems to be useful to children when attempting to explain 'dissolving'. The views on melting are presented later (event six). Very few of these young people had a picture of the dissolving process at a microscopic level. Views containing the statement "it just happens" were quite common in the responses to this focus question.

EVENT FIVE Blocks of ice are placed in a jar, the lid is screwed on, the exterior of the jar is dried with a towel, and the jar with its ice and lid, are placed to one side

This procedure took place at the beginning of the interview sequence. The interviewer made sure that the interviewee dried the outside of the jar, and was satisfied that the jar was dry on the outside. The jar was left to one side until its place in the interview schedule was encountered. This was after about 20 minutes.

The focus question here was (after the liquid which appeared was recognised as water) "where has the water on the outside of the jar come from?".

Some students were quite sure that the water (or sweat) had come through the glass. For example

> "The ice block pushes against the glass and the sweat probably goes through the glass and comes out on the sides."
> (101)

> "It's wet ... 'cause the ice changed to water and the vapour in the bottom of the jar is going through the glass ..."
> (124)

> "The ice has melted and it has made the glass cold ... and the water forms around the outside. (Where has the water come from?) When the ice melts. (How did the water get from the inside to the outside?) Through the glass. (Are you sure the lid's tight and it has not come over the top?) It is dry up top so it is only where the ice is. (You think it has come through the glass?) Yes ... it has come from inside and it has got colder." (138)

One student with this view was able to support the view with some knowledge of science

> "Oh well, it must have gone through the glass ... the particles of water they have gone through the glass ... like diffusion through air and that ..."
> LATER
> "(A lot of people I have talked to, younger children, are very worried about this, it troubles them a lot.) Yes, because they haven't studied the things like we have studied. (What have you studied which helps you?) At school? (Yes.) Things that pass through air, and concentration, and how things diffuse."
> (154)

Others considered that the coldness came through the glass and that this then created the water

> 'I think it came from the inside ... not in the sense that it goes from the inside of the glass to the outside. I think the coldness of whatever is inside, the ice, when it is so cold it is reacting with something like glass which can be hot or cold ..." (152)

> "... Because the water stays in there and just the coldness comes out and forms just, you know, steam water or something - ice water. (So does the steam water come through or just the coldness come through?) The coldness, and that makes the steam water." (106)

> "It is just ... inside it is so cold that it is just making it so the outside is cold ... the water is just being made there." (122)

> "... The air particles change state ... when the particles and molecules in the air ... react and hit - or actually come in contact with a cold being or body such as glass they are changed into a wet liquid substance." (152)

A number or responses could be classified as 'air' responses, but usually the child goes on to indicate that he has in mind some sort of condensation process, so these responses are grouped as "from water in the air".

> "Air that has gone onto the side of the jar has turned into water. (Where does the water come from?) The moisture in the atmosphere ..." (144)

> "It is wet ... the cold jar may have condensed some air on the outside ... it is colder than the air on the outside so it has condensed some of the water molecules from the air." (142)

> "It's cold, and moist. (Can you explain both of those?) Well, the ice cubes in there, they're frozen ice, frozen water and they're making the glass cold, and I dunno, I can't explain the moisture though." (132)

> "(What is this vapour?) It makes up part of the atmosphere ... it could be hydrogen and oxygen ... dry ... so you can't see it ... combining to form water on the edge of the glass." (173)

"Out of the air it condenses onto the sides. I think that (previously water) probably separated into hydrogen and oxygen gas and when it joins up again it turns back into water." (155)

These views can be summarised into six groups. In five of these groups the young person has a specific viewpoint on the origin of the water which has condensed on the chilled glass jar. There was one group who had no idea where the water had come from. In table form these views were:

TABLE 7

"Where has the water on the outside of the jar come from"

View	Responders
through the glass	101, 102, 124, 135, 139, 143, 152, 154, 158, 171
from coldness	081, 102, 103, 105, 106, 107, 137
from the air	152
from water in the air	142, 144, 156, 161, 162, 163, 165, 172
from hydrogen, oxygen	141, 151, 153, 155, 173
no clear views	104, 111, 121, 132, 133, 164

Some views indicated interesting ideas, which warrant further investigation. One example of this is the view that "coldness is in the ice" and "just the coldness comes out", suggesting that coldness is regarded as a substance.

Again we record the view that air is the gas form of water ("the air particles change state." - 152).

EVENT SIX A block of ice on a teaspoon is observed while it melts

Here the focus question was "what is happening to the ice?" Most of our sample had no difficulty in describing this event as "melting", and the interview schedule investigated children's views of ice melting. These views are of particular interest in this investigation because of the link between "melting" and "dissolving" which was commented upon earlier (Event four).

The following 10 year old showed a rather delightful egocentric viewpoint

> "It turns into water ... all it is ... it's just frozen water. (What's the difference between frozen water and ordinary water?) You can't drink it very good."[4]
> (104)

Some students could add little to their idea that "it just melts"

> "The ice gets hot ... it just melts."
> (102)

> "The ice melted ... when water is put in a certain degree it freezes ... when it is warmed up again it melts back into water." (131)

Some children use scientific terminology in a non-scientific way

> "The ice cube will dissolve then in the air."
> (107)

> "It's just sort of slowly evaporating into water."
> (143)

> "It's going to melt ... it is another form of the compounds breaking down ... it is another form of evaporation and condensation ..." (173)

Some see melting as a blending process, e.g.

> "Melting, breaking down ... it is not as cold as it should be to keep the ice all together. (What do you mean by breaking down?) Getting smaller ... the bits are just melting in with the water." (137)

A number of older students had ideas related to a particle model

> "(What happens to the particles in the ice when it changes into water?) They are the same particles but they are in a different state ... in the solid state they are kept together ... in the water state they are spread out ..."
> (154)

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4. In addition to this child centred view, one or two other students had the idea, that frozen, or recently melted water was unpleasant to drink, and they seemed to indicate that they had first hand experience. As well, one sixth former had been informed that recently melted water was so oxygen rich that skiers should not drink it.

"They break free, but then, why? The way I'm thinking they'd break free all along, all along right through the wall, and sort of, they'd move faster, like the forces between them wouldn't be so great, but there'd still be some, and they'd sort of slide down the wall and fall off."
(172)

"All the molecules of water ... they were all packed together but now ... as they get warm they move apart a bit."
(156)

"You know, the particles get tighter together."
(153)

Others use a general model which relates volume and temperature for many substances, but which like many of the particle models above is not adequate for water

"(What else happens when it melts?) It's going to be more ... if you took the volume of that (the water) it is going to be more. (Can you talk about what is happening in terms of molecules when it freezes?) They go more compact. (How do you see that?) The colder the heat the less vibrations there are between them ... so that is why the ice doesn't take up as much room as when it is a liquid or gas ..."
(151), also (152)

The term 'change of state' appeared infrequently. One view of this was

"... as they get heated up by the warm atmosphere they are moving around more rapidly and therefore changing state ..."
(152)

While another student was puzzled by this

"Mm, the model I've sorta got now ... ice cubes, rectangular shapes, rectangular wall, and just like say my water/gas model. <u>They break free, but then why?</u>"
(172)

Perhaps this student needed a concept provided by the <u>latent heat of fusion</u>? Another useful concept, hydrogen bonding, was not invoked by any of the eight students who would have been taught about it.

Others lacked any model, e.g.

"(How does it melt?) ... In the freezer, it's sort of got a dull look about it. But out, it's shiny, you can see it melting. (I'd really like to know some more about this melting process.) So would I." (171)

"Melting. (What does "melting" mean?) That's when the um ... there's not enough energy ... no ... it's enough energy now for the liquid to gain some kinetic energy and start moving around some more. As it moves around more it heats up and turns into a liquid. Slowly the molecules, the forces between each molecule is decreased and decreased ... it's hard to explain. The forces aren't great enough, the van der Waals forces, I don't know what the forces are between each molecule, are not great enough to hold them together, and they just kind of drop off into the liquid. (What do you know about van der Waals forces?) Not much, um ... I think it's something to do with the polarity ..."
(163)

And sometimes a model worked well:

"(What happens when ice melts?) Temperature increases. It ... water molecules get a greater kinetic energy. (So water molecules have got kinetic energy as well as gas ones?) Yes. (What about solid ones?) Um ... yeah, they do but it's very very low, that's why they don't move around at all. (So how does this help you understand melting?) What ... kinetic energy? Well, the lower the kinetic energy the less, the less if water molecules hit each other the less, the um the less the collisions going to be, it won't sort of bounce them off so much because it's got a low kinetic energy, and so they'd be closer together, and when they get to a solid state they'd sort of form bonds between each other. (Bonds. You mentioned bonds. What are these things?) I don't know whether they're bonds or not. But its the way that the solid forms, and packs together. Because its a slightly polar molecule the negatives will line up against the positive poles of each molecule." (162)

In summary form:

TABLE 8

"What is happening to the ice?"

View	Responders
it becomes water	104, 101
it melts and becomes water (incl: it gets warmer and it melts)	081, 103, 102, 107, 106, 105, 111, 123, 143, 144, 133, 155, 161, 111
it's above its melting temperature	122, 131, 126, 137, 138, 134, 135
the particles are no longer frozen together	141, 154, 163, 172
the heat makes the particles move apart	142, 151, 152, 153, 173, 162, 164, 165

Discussion

The set of events used in these interviews evoked a great deal of information from children and perhaps it would be appropriate at this stage of this paper to record some of the major viewpoints and impressions gained by the writers from this investigation.

One of the major impressions was that children can readily associate a technical term, often the appropriate technical term, with an event. The water "evaporates", "condenses" and "boils". On the other hand further questioning of children of all ages as to what they actually meant by these terms left us with a strong impression that even many older children had no sound scientific concepts underpinning these labels.

In some situations clearly identifiable "children's science" was established. For example, some young children can be characterized by having the views that the bubbles in boiling water are bubbles of air, that steam consists of hot air, and that air changes back to water on a cold surface. When water leaves a surface it reconverts back to air. In relation to these views some older children, who presumably have been exposed to the idea that water is made of hydrogen and oxygen and that air is made of oxygen and other gases, still retain their children's science view now supported with scientific information. To these children the bubbles in the boiling water are bubbles of hydrogen and oxygen, and that condensation and evaporation are respectively the combining and separating of hydrogen and oxygen gases. That such children's views can be modified by science lessons in ways not intended emphasises the need for us as teachers to be aware of children's views. With respect to the topic of physical change this also emphasizes that for some, possibly many children, the distinction between physical and chemical change is not a scientific distinction.[5]

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5. This point is considered further in the LISP Working Paper on Chemical Change.

While some older children had obviously been exposed to some particle model, two aspects of their model might be commented on. First, the idea of change of state being critically temperature dependent was not evident in the interviews. Melting, for example, was similar to dissolving in that to many children it is a gradual process almost unconnected with temperature. Secondly, the particle model appeared to be a rather abstract model to many children, hardly, if at all, related to reality. For example, the particle model for many children suggested that liquids would be less dense than solids, yet the only example of a liquid/solid change that they are familiar with defies that rule. This problem appeared to be ignored by teacher and student alike.

In our view, the particle model as it relates to physical change is a central aspect of the F1-4 Curriculum. The responses of those we interviewed to some very common events involving physical changes suggest that we should perhaps re-examine how and what we teach; particularly in terms of children's understanding of the associated technical language, their elementary ideas of physical change, and the relationship of these ideas to the children's everyday experiences.

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